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ZAMBIA ELECTRIFICATION GEOSPATIAL MODEL

EXECUTIVE SUMMARY

April 30, 2018

ACRONYMS

Acronym	Definition
REA	Rural Electrification Authority
RGC	Rural Growth Center
SAEP	Southern Africa Energy Program
SHS	Solar Home System
USAID	United States Agency for International Development
ZESCO	Zambia Electricity Supply Company

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1 EXECUTIVE SUMMARY

1.1 CONTEXT

At the request of the Zambian Ministry of Energy and the Rural Electrification Authority (REA), the United States Agency for International Development's (USAID) Southern Africa Energy Program (SAEP) has developed a geospatial model that determines the least-cost electrification solution for each household in Zambia. The model shows that development of mini-grids and installation of solar home systems (SHS) can play a significant role in electrification and replace grid extension for a substantial portion of the rural population.

The model provides a clean sheet, fact-based view of Zambia's least cost electrification options in order for Zambia to achieve universal access by 2030. It provides scenarios that reflect the impact of trends and change in assumptions and creates the flexibility to re-convene decision makers to review targets and strategies to achieve universal access as input assumptions and data vary over time (e.g., costs of technologies, new transmission and distribution infrastructure, etc.). It should be noted that the model does not provide technical recommendations nor does it create business cases for implementation agents, but rather can be used as a directional view on the optimal mix of technologies (according to least cost) and rough cost estimate of the investment envelop required. Given the first-stage nature of the model, it provides a directional view of a least-cost electrification plan but is not the Government of Zambia's electrification strategy. Together with the Ministry of Energy, the World Bank will be building on this model to develop a more detailed electrification masterplan for implementation in coming years. As such, use of this model for making strategic decisions or commercial investments is the sole responsibility of the user.

As the model is based on open source software and uses publicly available databases, it can be expanded and improved as required by the Ministry of Energy and REA.

1.2 HOW THE MODEL WORKS

The model layers demand, generation capacity and cost data from various sources, and adopts a six-step process to generate the least-cost technology by household. This is done by:

1. **Defining un-electrified households and clustering these into 'settlements'.** Two sources of data are used to triangulate whether households are electrified or not: nighttime emissions data and proximity to Zambia Electricity Supply Company (ZESCO) sub-stations.[1] Households are considered electrified if they emit nighttime light (above 50/225 on grayscale raster) or if they are within 2km or less from a substation. Using this methodology, the model finds an electrification rate of 32 percent, which is comparable to external sources (27 percent).[2] All households are then clustered into ~3,000 'settlements', which are pockets of density exceeding 0.5 persons per hectare. The

[1] Visible Infrared Imaging Radiometer Suite (VIIRS); ZESCO transmission map (2013); Energy Africa map of Zambia power infrastructure (2016)

[2] International Energy Agency (2015)

settlements are overlaid with the unelectrified population to identify and cluster all households that are currently un-electrified. The Zambian population is then divided as follows:

a. 'Standalone' areas, with fewer than 0.5 persons per hectare, account for 7.3 million people.

b. Rural settlements, with density between 0.5 and 5 persons per hectare, account for 3.7 million people.

c. Urban settlements, with density greater than 5 persons per hectare, account for the remaining 4.3 million Zambians.

Households in 'standalone' areas are automatically assigned solar home system (SHS) technology given the expense to connect such isolated households to a grid or mini-grid. The model considers changes in population density over time based on population growth and urbanization, whereby the population grows from 15 million in 2017 to 24 million in 2030.[3]

2. **Calculating unmet household demand as a function of pre-determined demand tiers, income level and migration across tiers over time** (i.e., increase in settlement income and consumption). Consumption levels are determined using the Energy Sector Management Assistance Program definitions of Tier Two (224 kWh p.a.), Tier Three (695 kWh p.a.) and Tier Four (1,800 kWh p.a.) demand. Based on median annual income, settlements are mapped to demand tiers with rural settlements classified as Tier Two, low income urban settlements as Tier Three and high income urban settlements as Tier Four. Consumption demand is grown over time based on household surveys (across 3,000 respondents in the DRC, Tanzania and Nigeria). These surveys indicate a migration of eleven percent of households from Tier Two to Tier Three every five years, and a migration of five percent of households from Tier Three to Tier Four. This provides a view on future demand growth linked to income growth.

3. **Determining the energy generation potential across four technologies, namely grid extension, solar mini-grid, hydro mini-grid and solar home systems.** The grid extension and mini-grid options are expected to meet all demand tiers, while solar home systems are currently only available in Zambia to service Tier Two and Tier Three demand. Potential to connect to existing grid infrastructure is determined by the location of sub-stations. No planned infrastructure is incorporated into model calculations, given uncertainty over when these plans would be realized. Technically feasible mini-grid hydro sites are determined as per the analysis done in the 2008 Rural Electrification Masterplan. The feasibility for mini-grid solar and SHS is determined using irradiation data, where the entire country is found to be conducive to solar generation with an irradiation range of 1,900 to 2,400 kWh/kWp of solar.

4. **Defining the optimal technology solution per household by comparing the lifetime cost per household for each technology** (driven by distance from the grid and aggregate demand in the settlement). A bottom-up cost is calculated for each technology based on five major cost categories: generation (capital and operating costs), distribution (capital and operating costs), household connection (i.e., metering and cabling (in some cases)), margins (inclusive of tariffs for grid and mini-grid) and appliances. The model uses a 20-year lifetime cost per connection per technology

[3] Central Statistics Office projections (2013)

type to select the optimal technology per household. The average costs by demand tier are given in the table below:

Table 1: Lifetime cost per connection (2030) by technology type, USD[4]

Technology	Tier Two	Tier Three
Grid	881	1,262
Solar mini-grid	966	1,381
Solar home system	606	2,693

The costs change over time as technology costs adjust. This is especially pertinent in the case of solar mini-grids where the cost of capital equipment is projected to fall by 50 percent between 2017 and 2030. As a result, the cost per connection in solar mini-grid falls by 25 percent for Tier Two and 38 percent for Tier Three by 2030, making it a much more competitive technology over time.

With a bottom-up cost per lifetime connection by technology type, the model can select the optimal technology per household at different points in time (2017, 2022 and 2030 are currently modelled). To validate these results, sensitivity analysis is conducted on each of the major input assumptions to provide assurance on the model logic.

5. **Adding productive use to residential demand, modelled as two scenarios (agricultural activity and Rural Growth Centers (RGCs)** impact the optimal mix of technologies.

   a. Agricultural activity like irrigation and maize milling can operate during household demand off-peak times[5], thereby potentially reducing household connection costs without increasing the capital outlay. This additional energy demand may make grid or SHS households switch to mini-grid given that the mini-grid costs can be spread over agricultural activity users and households[6].

      i. Maize milling potential for each settlement is calculated based on adjacent farmed land, provincial yield levels and share of locally ground maize. 3,200 settlements have some maize milling potential.

      ii. Irrigation potential is calculated based on adjacent farmed land, average crop mix and water requirement. Irrigation allows farmers to add another planting season leading to higher revenue. Only settlements within 5km of a surface water source (i.e. river or lake) are considered for irrigation; beyond this distance, the economics for the farmer / investor show decreasing returns. 600 settlements have some irrigation potential.

      iii. Milling and irrigation demands are then combined to identify settlements where the cost per connection is decreased due to agricultural activity.

   b. RGCs represent a significant source of energy demand: schools, health clinics, government buildings and some small-scale shops, have an estimated demand of ~35,000 kWh p.a. These

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[4] Grid connection cost based on 200 households in a settlement

[5] Irrigation activity assumed to rely on reservoirs, disconnecting water pumping to the reservoir from the actual irrigation timing.

[6] This cost reduction opportunity for households is only possible for densely populated settlements, where the cost of mini-grid distribution remains viable.

RGCs can either be served by grid or mini-grid. If they are grid connected, surrounding households also take up grid extension because only the reticulation cost (USD 241 per household) is incurred. In cases where RGCs are mini-grid-connected, households do not change their optimal mix: connecting these households to the RGC's mini-grid requires building extra capacity because they have similar consumption profiles, therefore the cost for these households remains the same.[7]

6. **Testing the sensitivity of key assumptions to provide assurance on the model**. Sensitivity analysis is conducted for four major input assumptions to validate the model robustness: the split between "stand alone" versus dense settlements; the split between urban and rural areas (5 persons per hectare in the base case); tier demand migration; and technology costs. Faster tier demand migration and changes in SHS and mini-grid costs are the most sensitive assumptions. Faster tier demand migration either from Tier Two to Tier Three or from Tier Three to Tier Four increases the share of mini-grid connections to 8 to 9 percent of the total new connections at the expense of SHS. Likewise, a 15 percent increase of SHS cost or a 15 percent decrease of mini-grid costs increases the share of mini-grid connections to 9 to 10 percent of the total new connections.

1.3 KEY FINDINGS

1.3.1 INSIGHTS FOR HOUSEHOLDS

Just over one million households are already electrified in Zambia, leaving 2.1 million households without access. This number is expected to grow to 3.5 million households by 2030. The least-cost technology mix to provide universal access to these unelectrified households differs by target year as shown in **Exhibit 1**. A snapshot of what universal access would look like at least cost in 2030 is also provided (**Exhibit 2**).

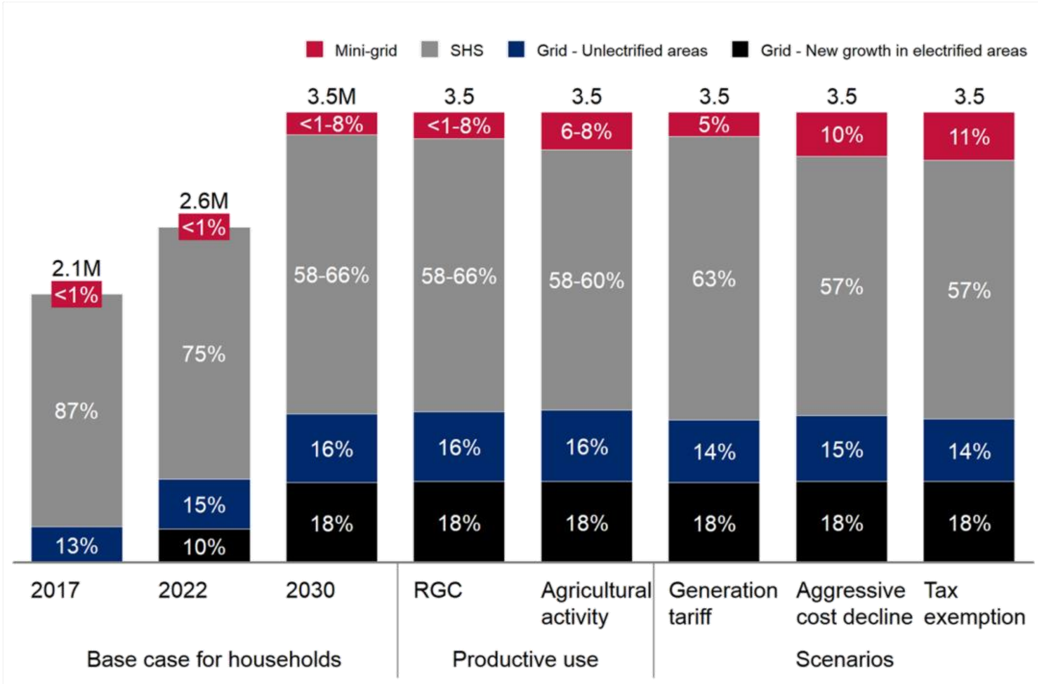
- In the immediate term, SHS and grid extension are the most affordable technologies for most households. For example, if all households were electrified by 2022 in Zambia, SHS would account for 75 percent of least-cost new connections (2.0 million households) and grid connections would account for 25 percent (0.6 million households).
- In 2030 this picture changes with declines in solar technology costs reducing the cost of mini-grids to allow them to compete with grid and SHS. SHS continues to be the most prevalent technology, accounting for 58 to 68 percent in the optimal mix (2.0 to 2.3 million households). Grid connections would account for 34 percent of newly electrified households (1.2 million households) where the increase is driven by population and urbanization growth in existing grid locations. Mini-grids have the potential to become cost-competitive, accounting for 1 to 8 percent of the optimal mix (5,900 to 0.3 million households). For the 0.3 million households, the cost difference between SHS and mini-grid is too small to justify the selection of one technology at the expense of the other.[8]

[7] Mini-grid costs increase linearly with the peak energy demand

[8] A range is provided for SHS and mini-grid connections because of the acute sensitivity in optimal solution to the relative cost of mini-grid and SHS.

- Approximately USD 4 billion (in 2017 real terms) would be needed to achieve this universal access target by 2030, with USD 3.3 billion (82 percent of the cost) being accounted for by SHS.[9]
- Consumer contributions (benchmarked at current levels) would cover USD 3.7 billion of the above-noted amount. However, the Government of Zambia may wish to explore changing this contribution over time given the substantial burden on SHS users (USD 3.3 billion).

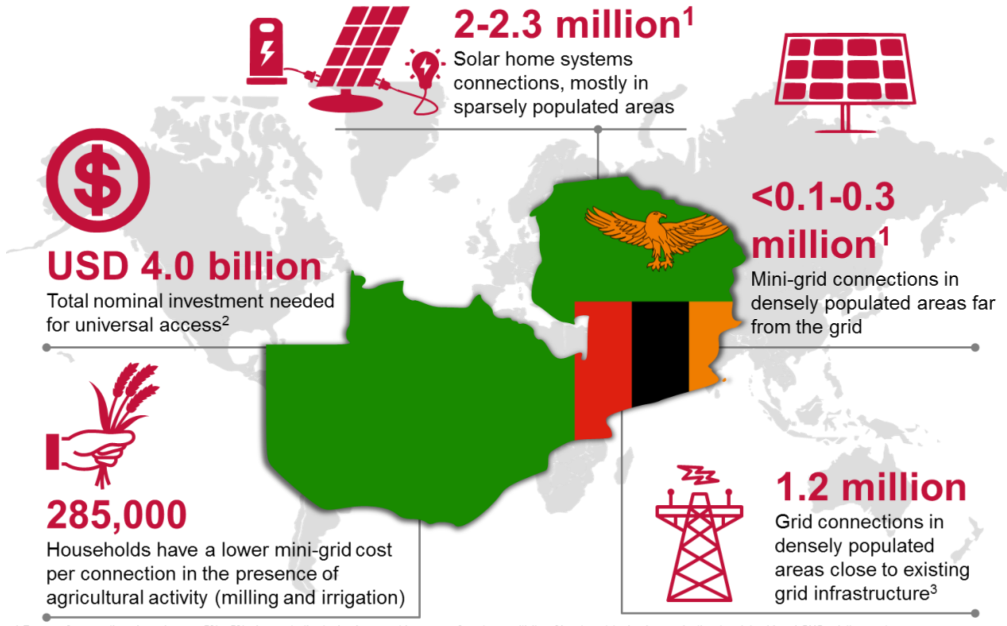
EXHIBIT 1: LEAST-COST TECHNOLOGY BY YEAR AND SCENARIO (% NEW CONNECTIONS)



SOURCE: Geospatial model

[9] These figures are calculated as the midpoint of the model results based on +15% and -15% of SHS and mini-grid variations to account for the acute cost sensitivity of these two technologies.

EXHIBIT 2: ZAMBIA'S SNAPSHOT FOR UNIVERSAL ACCESS BY 2030



1 Range of connections based on a +5%, -5% change to the technology cost because of acute sensitivity of least-cost technology selection to mini-grid and SHS relative cost
2 Calculated as pure cash cost; no borrowing fees included
3 Only existing sub-stations are considered in the base scenario of the model; sub-stations can be added as they shift from 'planned' to actual to update the model outputs over time

SOURCE: Geospatial model

1.3.2 INSIGHTS FOR PRODUCTIVE USE

Two cases for productive use are introduced as scenarios in the model, following requests by local stakeholders for these insights.

- Agricultural activity switches 285,000 connections (1,450 settlements) from SHS to mini-grid, mainly due to milling. However, settlements with irrigation activity benefit from a higher cost reduction (18 to 34 percent) than milling (1 percent), as milling demand per settlement remains low and only impacts those settlements that already had similar SHS and mini-grid costs. The result for milling is linked more closely to the acute sensitivity of the mini-grid costs (relative to SHS costs) than to the presence of milling activity. By contrast, irrigation has a greater impact on cost per connection. In addition, ~300 mini-grids could be built for irrigation with no cost reduction for households in "stand alone" areas.

- Providing power to the ~1,200 unelectrified rural growth centers (RGCs) identified by REA (either by grid or mini-grid) would see ~35 RGCs powered by grid (at least cost) and the remaining ~1,165 connecting to a mini-grid. Given the low share of grid uptake, the optimal technology mix for households remains unchanged. An insignificant number of households switch to grid, thereby keeping the grid share constant at 34 percent in 2030 (see **Exhibit 1**).

1.3.3 SCENARIOS

Three scenarios are modelled to account for potential shifts in assumptions (see **Exhibit 1**):

- Grid capital expenditure could be financed at a higher tariff to account for additional capacity to meet new connections. In the base case, the tariff is 7 US cents per kWh. One scenario models a cost-reflective tariff of 22 US cents per kWh. Even when these higher costs are included, the grid share sees a minor decline from 34 percent to 32 percent.

- Solar panel and storage costs could decline faster than anticipated. The base case already assumes a 50 percent capital expenditure cost decline, but some reports support an even greater decline of a further 10 to 20 percent. As a result, a 68 percent decline in capital expenditure costs is modeled as an 'aggressive' scenario, this increases the share of mini-grid to 10 percent of the total share.
- The government could give tax exemptions to mini-grid developers to make mini-grids more competitive in rural areas. If corporate tax to mini-grids is close to 0 percent, the share of mini-grid increases to 11 percent of the total share.

1.4 MODEL USE AND IMPLICATIONS FOR DECISION MAKING

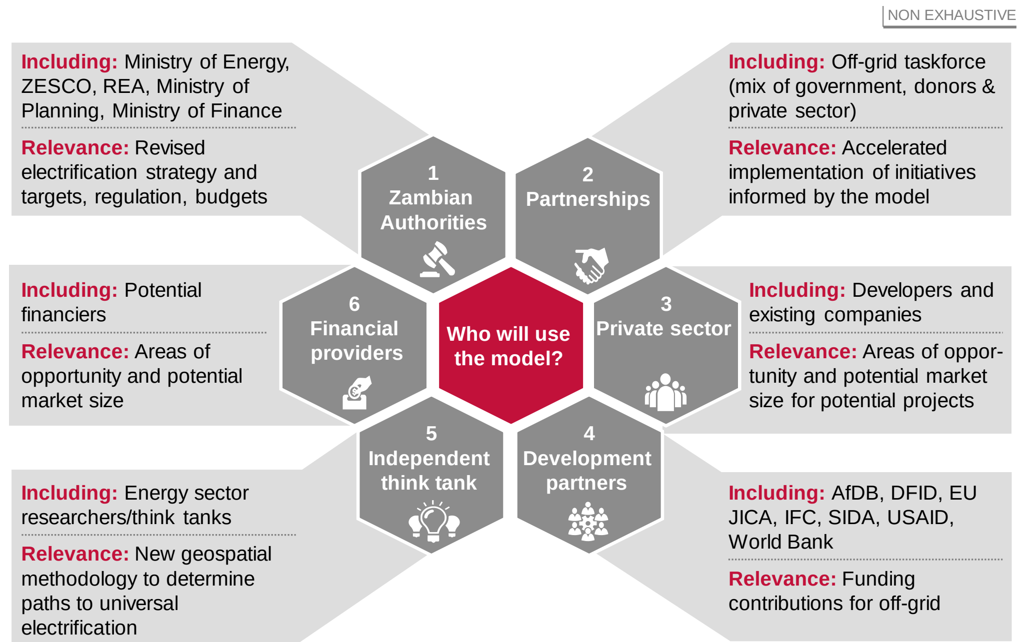
Going forward, the model will be owned by the Ministry of Energy and REA to inform their decision-making. In addition, the model will be used as a first stage version of the World Bank's detailed geospatial model and implementation plan as part of its National Electrification Strategy. There are significant opportunities for the model to help to shape electrification strategy, both with potential targets against technology types and a cost estimate.

Apart from providing possible electrification targets in an updated electrification strategy, the outputs from the model could assist in the Government of Zambia in strengthening the policy environment, improving regulation and determining the appropriate fiscal support.

- On the **policy** front, provide clear mandates to various government agencies to support the execution of an updated electrification strategy
- On the **regulatory** front, accelerate the definition of a concession model and grid interaction rules for mini-grids and remove barriers to SHS scale up (e.g., customs requirements)
- On the **fiscal** front, determine appropriate subsidies for the off-grid market and financial support for grid electrification

Beyond the Government of Zambia, the insights from this model could be used to prioritize initiatives under electrification partnerships (e.g., off-grid taskforce), identify areas of opportunity for private sector players and financiers, size impact and budget for development partners and contribute towards developing electrification geospatial methodologies. **Exhibit 3** provides an overview of the possible use of this model to convene and engage stakeholders.

EXHIBIT 3: KEY MODEL USERS



SOURCE: Interviews, Team analysis

To aid use of the model across all stakeholders, all model materials have been publicly released along with this executive summary. With access to these materials, any user will not only be able to view and use the results, but also adjust assumptions to see how the results shift.

Materials for use include (see the appendix with the relevant links to access these materials and how to use these materials):

- **A detailed overview of the model**, including context, how the model works, key findings, and an appendix with all assumptions and data sources
- **Model results** for each settlement in each base case (2017, 2022, 2030) and all scenarios in Excel
- **Google Earth files** that show many of the key inputs (e.g., electrified household, settlement areas, sub-station locations) and results (e.g., base case results for 2017, 2022, 2030)
- The **full coding model** in Python, including all input files needed to run and adjust this model

2 APPENDIX: HOW TO USE THE MODEL

There are four types of files that accompany this executive summary to allow users – across the public and private sector – to access the model output and use it to inform their respective activities going forward. Table 1 sets out the materials, with each file name, format and description. To download the files, please click here (copy the file to your computer and extract its contents).

For each material type, further instructions to enable use are provided in subsequent sub-sections.

Table 1: List and description of all supporting materials to enable model use

Material type	File name	File format	File description	File name[10]
Detailed overview of the model	SAEP Zambia Geospatial Model Overview Document	PDF	Overview document to provide model context, methodology, base case results, use cases and input assumptions	1. Overview of the model
Model results	SAEP Zambia Geospatial Model Results	Microsoft Excel	2017, 2022 and 2030 least-cost technology solution for each settlement	2. Model results by settlement
Google Earth files	Currently Electrified	Google Earth	Map of all currently electrified areas in Zambia	3.1 Currently Electrified.kmz
	Substation Points	Google Earth	Locations of all ZESCO substations	3.2 Substation Points.kmz
	Populated Places	Google Earth	GeoNames.org locations of ~13,800 populated places in Zambia	3.3 Populated Places.kmz
	Settlements	Google Earth	Locations of all populated places with density greater than 0.5 persons per hectare	3.4 Settlements.kmz
	Urbanicity	Google Earth	Locations of all populated places that are urban (i.e. have a density greater than 5	3.5 Urbanicity.kmz

[10] This is the name of the folder in "Geospatial Model_Main Release.zip"

Material type	File name	File format	File description	File name[10]
			persons per hectare)	
	Base Case Results 2017	Google Earth	Least-cost technology per populated place for 2017	3.6 BaseCaseResults_2017.kmz
	Base Case Results 2022	Google Earth	Least-cost technology per populated place for 2022	3.7 BaseCaseResults_2022.kmz
	Base Case Results 2030	Google Earth	Least-cost technology per populated place for 2030	3.8 Base Case Results 2030.kmz
	Settlements Switching to Mini-Grid with Agricultural Activity	Google Earth	Locations of all settlements that could switch from SHS to a mini-grid with irrigation and milling activity	3.9 Settlements Switching to Mini-Grid with Agricultural Activity.kmz
	Stand-alone Agricultural Mini-Grids	Google Earth	Locations of all 'stand-alone' areas that could support a mini-grid with irrigation and milling activity	3.10 Stand-alone Agricultural Mini-Grids.kmz
Full coding model	N/A	Python	Full model to combine all inputs to output least-cost technology per settlement in Python	4. None – available on request (see **section 2.4** below)

2.1 DETAILED OVERVIEW OF THE MODEL

This document contains the following chapters to provide the user with an overview of the methodology, base case results, potential use cases and all major assumptions. The chapters of this document include:

- **Context,** outlining the impetus behind the model and the top-line results around the least-cost technology mix to achieve universal access in Zambia in 2030
- **How the model works,** detailing the six-step methodology taken to identify the least-cost technology per unelectrified household

- **Insights for households,** sharing the base case results for the least-cost technology mix for purely residential demand at different points in time (2017, 2022 and 2030)
- **Insights for productive use,** putting forward two types of productive use, namely agricultural activity and rural growth centres, and demonstrating how productive use inclusion adjusts the optimal technology mix
- **Scenarios,** providing three scenarios – a cost-reflective grid tariff, a more aggressive solar capital equipment cost decline, and mini-grid tax exemption
- **Model use,** suggesting potential avenues for model use by various stakeholders once the model is released
- **Appendix A: Stakeholder engagement and reports,** which lists all of the stakeholders engaged to date and reports used to construct the model
- **Appendix B: Detailed input assumptions,** which lays out all assumptions and data sources used in each of the six steps of the methodology

2.2 MODEL RESULTS (IN EXCEL)

An Excel file of all of the model results is available, including the base case results and different scenarios. **Table 2** summarizes the full suite of results that can be found in the Excel.

Table 2: Contents of the model results Excel file

Tab	Description
Base Case 2017	Base case results for 2017
Base Case 2022	Base case results for 2022
Base Case 2030	Base case results for 2030
Aggressive Solar Decline 2022	Results for solar capex decline in 2022
Aggressive Solar Decline 2030	Results for solar capex decline in 2022
Cost Reflective Tariff 2022	Results for cost-reflective grid tariff in 2022
Cost Reflective Tariff 2030	Results for cost-reflective grid tariff in 2030
No Mini-Grid Tax 2022	Results for full tax exemption (0%) for mini-grids in 2022
No Mini-Grid Tax 2030	Results for full tax exemption (0%) for mini-grids in 2030

In each of the aforementioned results tabs, a single row represents a settlement. For each settlement, the following information is provided:

Table 3: Definitions for each field in Excel results file[11]

Field	Relevant Column	Unit of measure	Field description
ID	A	N/A	Unique identifier for a specific populated place (from GeoNames.org)
Latitude	B	Degrees	Latitude of settlement in WGS84 coordinates
Longitude	C	Degrees	Longitude of settlement in WGS84 coordinates
Province	D	N/A	Province name of settlement
District	E	N/A	District name of settlement
Locality	F	N/A	Area name of settlement (taken from GeoNames.org)
Population	G	Number	Number of people in area
Households	H	Number	Number of households in area
Demand	I	Kilowatt hours	Total residential demand of area
Grid cost	J	USD	Total cost to electrify area with grid extension
Mini-grid cost	K	USD	Total cost to electrify area with mini-grid
SHS cost	L	USD	Total cost to electrify area with solar home systems

[11] Relevant for all results tabs of the Excel from “Base Case 2017” onwards

Field	Relevant Column	Unit of measure	Field description
Distance to grid	M	Kilometers	Distance to nearest low-voltage substation
Settlement density	N	Dense/Sparse	Field indicates area is dense (if density exceeds 0.5 persons/ha) or sparse (if below threshold)
Lowest cost technology	O	Technology choice	Least-cost technology (Grid, MG (solar mini-grid), SHS)
Lowest cost	P	USD	Total cost for least-cost technology solution

2.3 MODEL RESULTS (IN GOOGLE EARTH)

All of the model results can be visualized using Google Earth. The user will need to first download Google Earth software (which is available for free online), and then download the specific files listed in Table 1.

2.3.1 USING THE GOOGLE EARTH FILES

2.3.1.1 Steps to use the files

The steps for using the Google Earth files are provided below:

Step 1: Download the Google Earth software online using this link: https://www.google.com/earth/download/gep/agree.html

Step 2: Download the Google Earth files listed in Table 1 above.

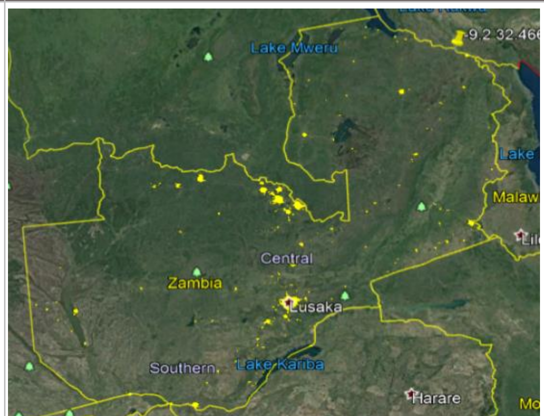
Step 3: Drag and drop each file into Google Earth. These files will appear in the "Places" tab on the left-hand side of your screen once you have been successful.

Step 4: Check the box next to the file that you would like to visualize under the "Places tab".

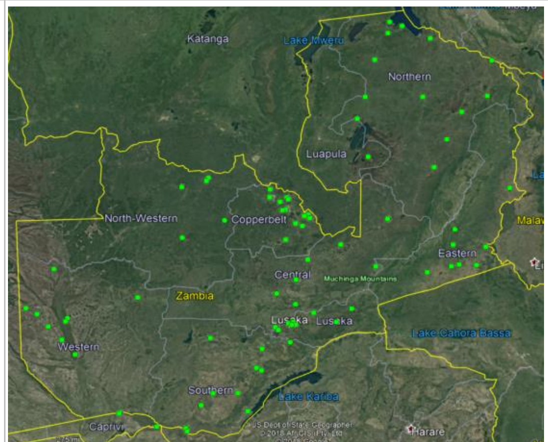
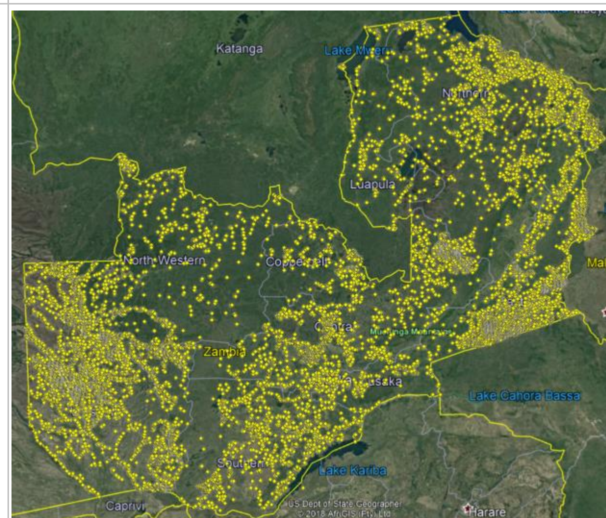
2.3.1.2 What the user can expect to see

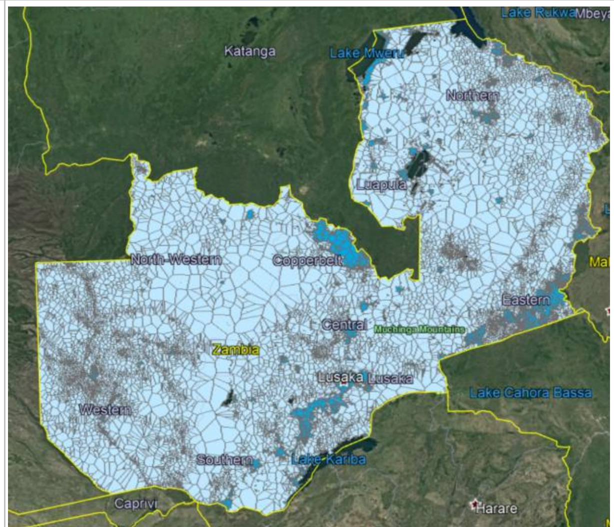
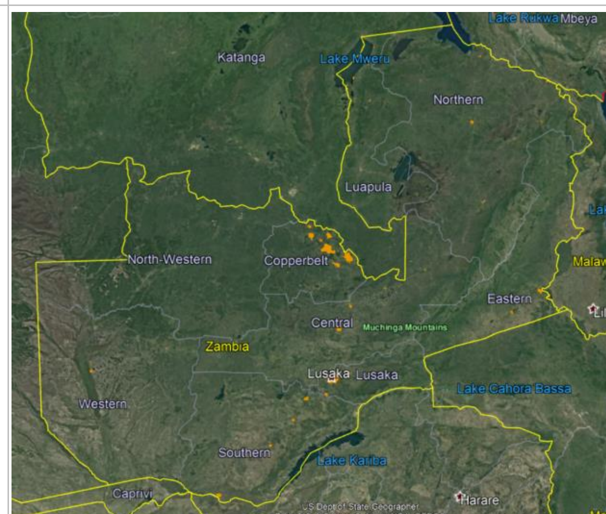
Table 4 provides pictures of what the user can expect to see for each selected file type, with a copy-and-pasted Google Earth image for each of the Google Earth files.

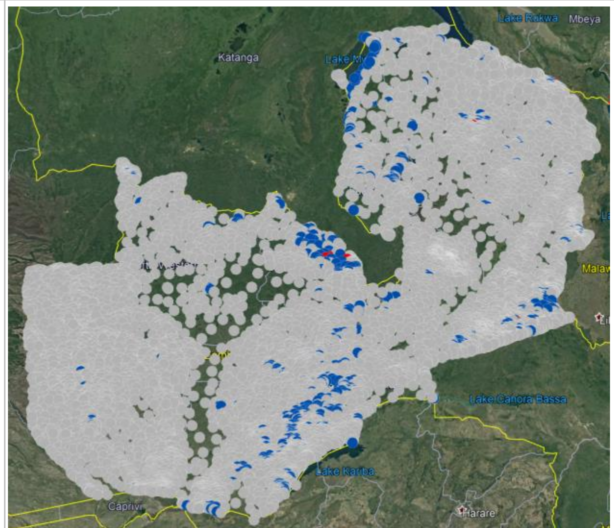
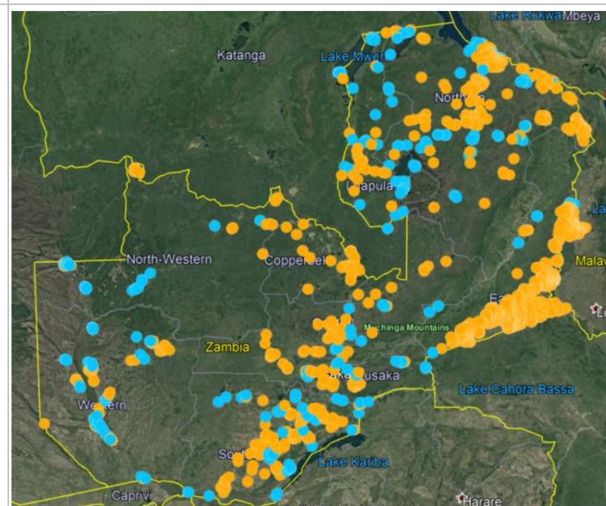
Table 4: Description of Google Earth files

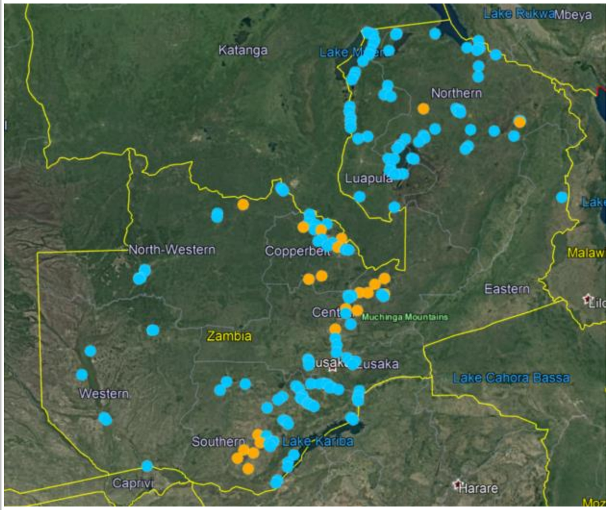
File name	File description	Relevant page in model overview[12]	Google Earth image	What the map images mean
Currently Electrified	Map of all currently electrified areas in Zambia	Page 14		The yellow areas are all of the areas that are currently electrified

[12] This field provides the page in the model overview which references this input or output (now seen in Google Earth format)

File name	File description	Relevant page in model overview[12]	Google Earth image	What the map images mean
Substation Points	Location of all ZESCO substations	Pages 14 and 32		All of the green dots are locations of low-voltage substations
Populated Places	GeoNames.org locations of ~13,800 populated places in Zambia	Page 16		Each yellow dot is a 'settlement' identified using GeoNames.org with a certain population

File name	File description	Relevant page in model overview[12]	Google Earth image	What the map images mean
Settlements	Locations of all populated places, broken up by those of density greater than 0.5 persons per hectare, and those less than 0.5 persons per hectare	Pages 17 to 19		Each polygon shape is a certain settlement area, with darker blue areas showing the dense areas where population density is above 0.5 persons/ha
Urbanicity	Locations of all populated places that are urban (i.e. have a density greater than 5 persons per hectare)	Pages 18 and 20		The orange areas are the urban areas where population desnity exceeds 5 persons/ha

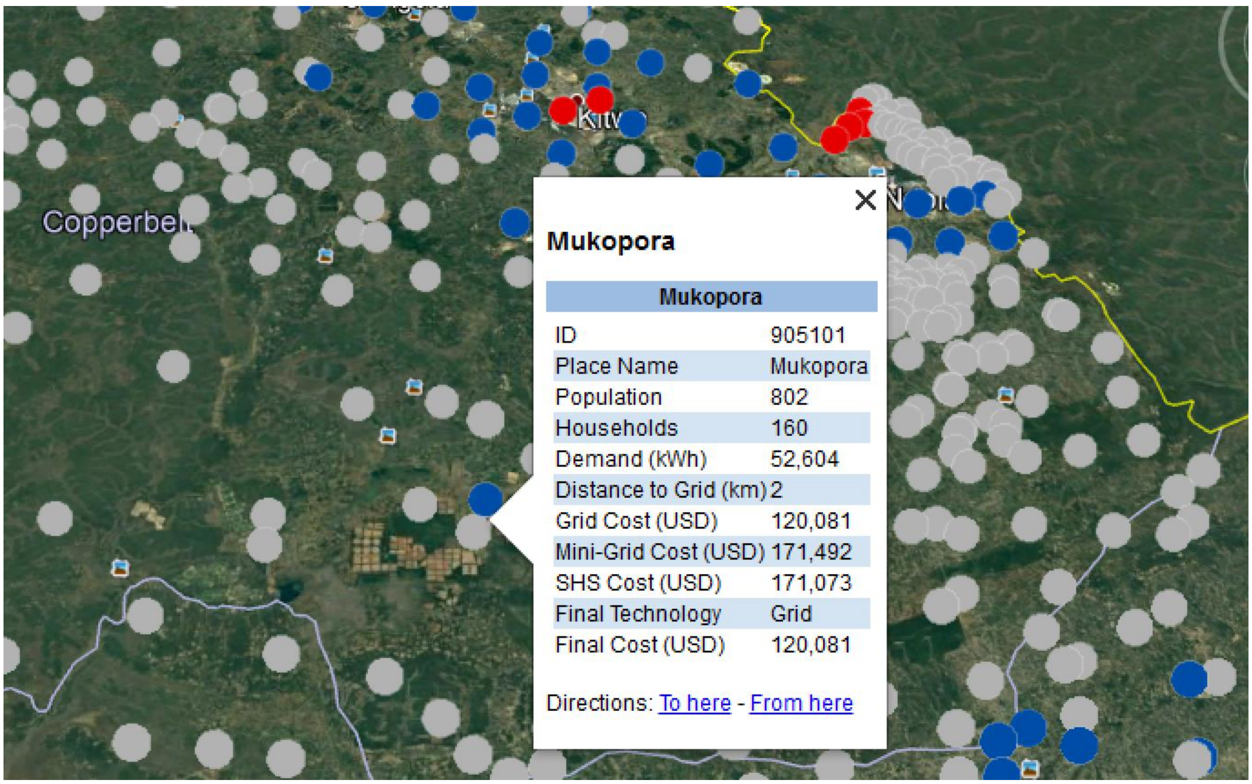
File name	File description	Relevant page in model overview[12]	Google Earth image	What the map images mean
Base Case Results 2017 / 2022 / 2030	Least-cost technology per populated place for 2017, 2022 and 2030	Pages 76 and 77		Each of the dots is a certain location, with grey areas indicating SHS, blue areas indicating grid, and red indicating mini-grid
Settlements Switching to Mini-Grid with Agricultural Activity	Locations of all settlements that could switch from SHS to a mini-grid with irrigation and milling activity	Page 90		Each orange dot is a site switching to a mini-grid due to milling demand; each blue dot is a site switching to a mini-grid due to irrigation demand

File name	File description	Relevant page in model overview[12]	Google Earth image	What the map images mean
Stand-alone Agricultural Mini-Grids	Locations of all 'stand-alone' areas that could support a mini-grid with irrigation and milling activity	Page 93		Each orange dot is a site in a 'stand alone' area that can support a mini-grid for milling; each blue dot is a site that can support a mini-grid for irrigation

2.3.2 SEEING INDIVIDUAL SETTLEMENTS

In the 'Base Case Results' Google Earth file, the details and optimal technology for each area can be viewed. The user can zoom in to specific areas on the map and select one of the 'dots' that represents a settlement. An example is provided in **Exhibit 4** below. The settlement name is provided, along with demographic details (population, number of households), the distance from to the grid, and the comparative costs by technology type.

EXHIBIT 4: SAMPLE VIEW OF INDIVIDUAL SETTLEMENT IN GOOGLE EARTH



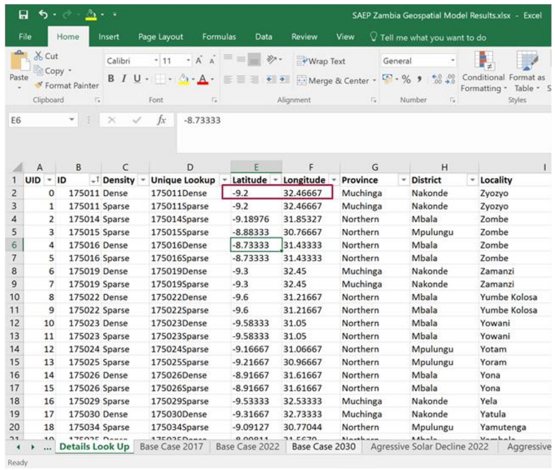
2.3.3 USING THE MODEL RESULTS EXCEL FILE WITH THE GOOGLE EARTH FILES

To use the Excel file together with the Google Earth files, the "Details Look Up" tab of the excel must be used. The latitude and longitude coordinates from the Excel can by copied into the "Search" bar of Google Earth (with a space between the latitude value and the longitude value). **Exhibit 5** below demonstrates this step visually. The user can then move between the Excel and the Google Earth files.

EXHIBIT 5: STEPS TO LINK EXCEL RESULTS TO GOOGLE EARTH RESULTS

Step	Screenshot	Specific instruction
Step 1: Identify the area you want to look at in Excel	(see screenshot below)	Find the location's latitude and longitude coordinates in the "Details Look Up" tab: ▪ Latitude: -9.2 ▪ Longitude: 32.46667
Step 2: Locate that area in Google Earth	(see screenshot below)	Enter the co-ordinates, separated by a space, in the "Search" tab in the top left corner of the screen

Step 1: Identify the area you want to look at in Excel

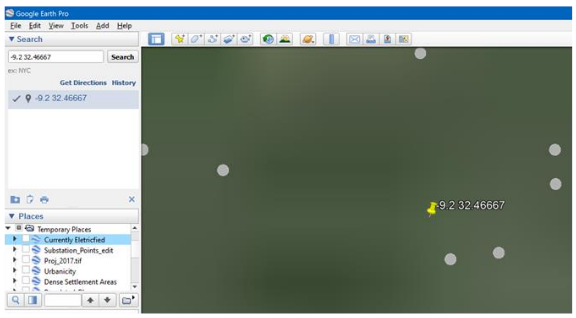


	A	B	C	D	E	F	G	H
1	UID	ID	Density	Unique Lookup	Latitude	Longitude	Province	District	Locality
2	0	175011	Dense	175011Dense	-9.2	32.46667	Muchinga	Nakonde	Zyozyo
3	1	175011	Sparse	175011Sparse	-9.2	32.46667	Muchinga	Nakonde	Zyozyo
4	2	175014	Sparse	175014Sparse	-9.18976	31.85327	Northern	Mbala	Zombe
5	3	175015	Sparse	175015Sparse	-8.88333	30.76667	Northern	Mpulungu	Zombe
6	4	175016	Dense	175016Dense	-8.73333	31.43333	Northern	Mbala	Zombe
7	5	175016	Sparse	175016Sparse	-8.73333	31.43333	Northern	Mbala	Zombe
8	6	175019	Dense	175019Dense	-9.3	32.45	Muchinga	Nakonde	Zamanzi
9	7	175019	Sparse	175019Sparse	-9.3	32.45	Muchinga	Nakonde	Zamanzi
10	8	175022	Dense	175022Dense	-9.6	31.21667	Northern	Mbala	Yumbe Kolosa
11	9	175022	Sparse	175022Sparse	-9.6	31.21667	Northern	Mbala	Yumbe Kolosa
12	10	175023	Dense	175023Dense	-9.58333	31.05	Northern	Mbala	Yowani
13	11	175023	Sparse	175023Sparse	-9.58333	31.05	Northern	Mbala	Yowani
14	12	175024	Sparse	175024Sparse	-9.16667	31.06667	Northern	Mpulungu	Yotam
15	13	175025	Sparse	175025Sparse	-9.21667	30.96667	Northern	Mpulungu	Yoram
16	14	175026	Dense	175026Dense	-8.91667	31.61667	Northern	Mbala	Yona
17	15	175026	Sparse	175026Sparse	-8.91667	31.61667	Northern	Mbala	Yona
18	16	175029	Sparse	175029Sparse	-9.53333	32.53333	Muchinga	Nakonde	Yela
19	17	175030	Dense	175030Dense	-9.31667	32.73333	Muchinga	Nakonde	Yatula
20	18	175034	Sparse	175034Sparse	-9.09127	30.77044	Northern	Mpulungu	Yamutenga

Find the location's latitude and longitude coordinates in the "Details Look Up" tab:

- Latitude: -9.2
- Longitude: 32.46667

Step 2: Locate that area in Google Earth



Enter the co-ordinates, separated by a space, in the "Search" tab in the top left corner of the screen

2.4 SOURCE CODE

The model has been written in two pieces: an initialization script which processes the raw inputs and creates a number of intermediate outputs, and an optimization script which calculates out cost for each electrification technology in a settlement and identifies the lowest cost network configuration.

Both scripts were written in Python 2.7 for compatibility with several packages. All referenced packages are open source and free to use; a full list is included in the source code. To execute modeling code, users must have a Python 2.7 install, the detailed packages, and valid paths to the appropriate input files. Further input parameters are listed within the source code; customization and updates may require changes to these values. Further details are included in in-line code comments.

All model inputs are assumed to have a WGS84 projection. Inputs in other projections must be preprocessed or they will not overlay correctly.

The full code base is available on request from USAID SAEP (contact cvandevelde@deloitte.com for access).